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BEACH NOURISHMENT PROJECT

CAPE HATTERAS, NORTH CAROLINA

POST-PUMPING SUMMARY

NOVEMBER 1973

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BEACH NOURISHMENT: BUXTON, NORTH CAROLINA

POST-PUMPING SUMMARY

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INTRODUCTION

In 1972 the authors of this report undertook a research program designed to assess the impact of a large sand nourishment project on the physical and biological elements of the beach system at Cape Hatteras, North Carolina. The field program was under the supervision of Mr. Preston Riddel (NPS) and the laboratory and data analyses were conducted under the direction of Robert Dolan.

Since all aspects of the physical and biological environments could not be monitored, a set of best "indicators" was selected and measured throughout the period of nourishment. The eleven basic questions answered during the course of the investigation are included as the second part of this report.

BACKGROUND

Public concern about shoreline recession in the Cape Hatteras area can be traced back to the initial development (subdivision) of the beach-front land along the Outer Banks during the 1930's and 1940's. Serious problems were inevitable as the erosional forces along the mid-Atlantic are highly variable and time-dependent, yet the line of man's development, once it had been established, remained fixed.

Narrowing of the distance between the line of development and the active surf-zone at Cape Hatteras

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reached a critical point during the mid-1960's. Large segments of the man-made barrier dunes, which had been constructed in the late 1930's, were lost and oceanic overwash became a constant threat. The distance between the Cape Hatteras Lighthouse and the surf zone reached 256 feet in 1966. With reversal of this trend unlikely and relocation of the shoreline developments virtually impossible, the National Park Service contracted in 1966 to have 312,000 cubic yards of sand placed along the beach areas of greatest concern. The material for this restoration program was extracted from a large sound-side tidal delta that had been deposited by an inlet during the Ash Wednesday storm of 1962. However, the borrow material was too fine to remain as part of the subaerial beach system and the quantity was far too small to have significant impact on the inshore bar-trough system.

By 1967 continuous erosion had placed the Cape Hatteras Lighthouse and the U.S. Navel facility at Buxton in positions vulnerable to wave and surge forces. Following the recommendations of the Coastal Engineering Research Center, Army Corps of Engineers, the U.S. Navy contracted to have three permanent groins constructed within the problem area during the summer of 1969.

The groins, which required several adjustments in design, did provide protection for the Navy Facility and the Cape Hatteras Lighthouse; however, the adjacent shorelines, both to the north and south of the groin field,

continued to recede at rates equal to or in excess of those recorded earlier. The National Park Service continued a "hold-the-line" strategy using sand bags and spot-dune construction.

During the winter of 1970, the erosion problem north of the Cape Hatteras Lighthouse became so severe that another beach-nourishment project was planned and implemented. Instead of returning to the 1966 project borrow site, the Pamlico Sound tidal delta, sand was extracted from the Cape Point spit.

This 1971 nourishment was effective in that the material remained on the beach for a longer period of time; however, the 500,000 cubic yards added during the 1971 project, although nearly double the amount added in 1966, was still too small a quantity for major impact on the beach system. The present project was designed for a sufficient volume of material (1,250,000 cubic yards) to have much greater impact.

The Cape Point spit borrow site has proven to be an excellent source of nourishment material. Analysis of more than 5,000 sediment samples, collected from the discharge points and from adjacent sites reflective of natural conditions, indicated that it is virtually impossible to separate the nourishment material from the natural beach sands.

SPECIFIC QUESTIONS

Indicators of the environmental impact of a beach nourishment project can best reflect the biophysical modifications of the system if the most "dynamic" elements are included in the design. We selected the following:

1. Configuration of the subaerial beach and the inshore bar-trough system.
2. Sediment characteristics.
3. Storms and waves.
4. Beach-face organisms.

The design was simple. We sampled for several weeks before the pumping began to establish the "standard" for natural conditions. This was then followed by systematic measurements throughout the pumping period. In this way the beach characteristics before pumping were compared with the same characteristics as measured during the nourishment period. In addition, samples of sediment, topography, and organisms were collected in natural beach areas adjacent to the impacted areas for "within pumping" comparisons. Although the environmental impact of the beach fill is the primary goal of the monitoring program, an important secondary goal is to determine the relative effectivensss of the project. Questions concerning effectiveness can also be answered from the same data sets obtained for the impact analysis.

THE MEASUREMENT PROGRAM

To document the environmental impact (geologic and ecologic) of the beach restoration program, these data sets were collected:

A. Pre-nourishment:

  - [1] Offshore bathymetry (bars-troughs).
  - [2] Beach configuration, both plain view and profile.
  - [3] Beach-face sediment characteristics.
  - [4] Borrow material characteristics.

B. During the Fill Operation:

  - [1] Samples of the material discharged onto the beach (about 1 sample per 2,000 yards).
  - [2] Sampling comparisons of differences between the fill and the natural beach sands.
  - [3] Systematic measurements of changes in beach and inshore configuration by surveying and aerial photo interpretation.

C. Trends in Storm and Wave Action:

  - [1] Emphasis was placed on winter storms since they are the major cause of beach erosion.

RESULTS

Our analysis of these pre-nourishment and nourishment data sets provide the following answers (preliminary) to the questions concerning environmental impact

of the beach fill. More detailed statements are included in the sections following this summary.

1. Overall Effectiveness -- if retention and compatibility of the fill material are a good measure of beach nourishment effectiveness, the project was clearly successful. Retention figures averaged consistently above 90%, and sediment sampling indicated insignificant differences between the fill material and the native sands; however, this does not mean that the sediment will remain in the system for a great length of time. A rough estimate is that after two to three years the impact of the fill will be very difficult to detect. (See next section).

2. Configuration -- the 1,250,000 yards of beach fill had major impact on the subaerial beach. At times the beach was built-out up to 300 feet, and the overall "bulge" of material could be clearly seen from the air and at ground level as a distinct protrusion of the shoreline. This build-out was into the pre-nourishment inshore zone, mostly resulting in the seaward displacement of the inshore trough. Our fathometic profiles did not indicate any significant alteration of the offshore bar-trough. The water depths beyond approximately 500 feet offshore remained consistently deep throughout the pumping period. We consider this to be of major significance--more details on this topic are presented in a separate paper (Appendix II).

3. Ecology -- other than the expected elimination of great numbers of the common subaerial ghost crabs, the ecological impact of the fill appears to have been minor. We have attached a report (Appendix III) concerning the displacement of *Emerita talpoida*, and general field ovservations suggests that shore birds were as abundant in the impacted areas as they are in adjacent areas. Finally, surf fishing in the Cape Point region seemed little affected by the addition of the sand into the inshore system.

4. Borrow Pit -- perhaps the single most negative environmental aspect of the beach nourishment project is the residual borrow pit on the Cape Point spit. This feature is not only unsightly, but it is clearly a hazard. Hopefully, a series of large northeast storms will soon overwash the beach-face in the borrow pit area, filling in the scar of the project. This will happen, as it has in the past, the only question is when.

5. Storms and Waves -- in general, this past year was very mild in terms of destructive northeast storms. Specifically during the period January 1 through October 1, 1973:

[1] During 7 of the 9 pumping months we had fewer than the average long-term monthly number of storms ($\geq$ 5 ft.).

[2] No year in the last three decades had fewer storms for the equivalent period (14 versus an average of 24.7).

[3] For 95% of pumping period between March 1 and October 1 -- no year had fewer storms (7 versus an average of 15.7 per year).

[4] For the storm record period October 1, 1972, through October 1, 1973, only three years had fewer storms during the equivalent time period (1972-73 had 27 storms).

[5] Only two storms occurred with return intervals greater than 1 year (February 9-15, 1973, and March 21-24, 1973). All other storms had return periods less than .65 years.

[6] Only 1 hurricane generated waves ≥ 5 ft. and this storm was so far offshore that only long deep-water swell reached Cape Hatteras.

[7] Hurricane Gilda did, of course, result in large waves and surge; however, this storm occurred well into the "post-nourishment" period; thus, it will be included in the post-nourishment phase of our reports.

POST-NOURISHMENT PLANS

Now that the 1,250,000 yards of nourishment has been added to the system with retention (estimate) of approximately 80 to 90 per cent, the next set of questions concerns the continued impact and its effectiveness. Our measurement program will include continuation of the subaerial beach sampling (profiles, sediment, and organisms), offshore fathometic profiles, and analysis of storms and waves. Attempts will be made to correlate the frequency and magnitude of storms with changes in the newly placed fill material.

CAPE HATTERAS BEACH NOURISHMENT PROJECT

PROGRESS REPORT FOR NOVEMBER, 1973

1. What storm and wave conditions have characterized the pumping period? Were the storm and wave conditions significantly different than similar months of recent years?

Answer: The storm and wave conditions that occurred during the period of beach nourishment may best be characterized as consisting of two widely differing periods. The first period, up to the end of March, was considerably stormier than the average for the last three decades. The second period, extending from April 1 to October 1, was the calmest equivalent time period in the last 30 years (see Fig. 1). Of the seven times on which overwash in the Buxton area was observed, two occurred prior to the start of pumping and five occurred during the early stormy phase (January through March). The storm of February 9-15, 1973, was the most severe storm during the pumping period and the recurrence interval for storms of its magnitude is once in twenty-eight years. In spite of the severity of storms during the January through March period, the number of storms were few by comparison with the 30 year average (1942-1972).

The second, calm, portion of the pumping interval was the calmest on record with all months except July

being below the 30 year average. It was during this exceptionally calm period that the bulk of the sediment was pumped (Table I).

Only the three months preceeding the pumping October, November, and December of 1972 had significantly more storms than the long-term average. In Figure 2 the storms of the period October 1, 1971 through October 1, 1973 are plotted on the return interval curve for the decade.

Hurricane Gilda passed offshore from Cape Hatteras on October 24, 1973, approximately five weeks after the pumping was completed. At the time of this report waves and surge for this storm had not been analyzed; however, a brief description of this storm's impact was provided by Mr. John Ponton and is included as Appendix I.

2. How often did storms generate surge and waves of sufficient magnitude to cause erosion of the dunes and overwash? What were the storm conditions and what was the duration of the overwash sea state?

Answer: As mentioned in question No. 1, seven storms were large enough to generate significant overwash. Of the seven two occurred prior to pumping and five occurred during the early stormy phase of pumping. During the calm summer month only Hurricane Alice generated significant waves (as swell). Slight overwash into the borrow pit was observed during this event. Hurricane Gilda (October 24-27) resulted in

TABLE I

FREQUENCY OF STORMS GENERATING DEEP WATER WAVES 5 FEET HIGH AND LARGER BY MONTH FOR THE CLIMATIC NORMALS, FOR 1972-1973 AND THE DIFFERENCES

	Average # Storms For (1942-1973)	# Storms 1972-1973	Difference
Oct.	2.6	4	+1.4
Nov.	3.0	5	+2.0
Dec.	3.6	4	+0.4
Jan.	4.5	3	-1.5
Feb.	4.3	4	-0.3
Mar.	4.6	2	-2.6
Apr.	3.9	2	-1.9
May	2.0	0	-2.0
June	1.2	0	-1.2
July	0.8	1	+0.2
Aug.	1.1	0	-1.1
Sept.	2.0	2	0
SUM	33.6	27	-6.6

overwash into the motel area, but did not cause extensive erosion of the existing dunes. The major impact of this storm action was the movement of a significant amount of sediment from the active beach-face of the fill into a series of depression immediately behind the fill berm (see Figure 3 and Appendix I).

3. How often did overwash occur in the borrow pit? What configuration changes have occurred?

Answer: The history of overwash into the borrow area during the period October 1, 1972, through September 30, 1973, is closely tied to the two dissimilar periods of storm activity. Overwash events in the borrow area were restricted to the period of above normal period in terms of number of storms (October, November and December) and the above normal period of storm intensity (January, February and March). The period April through September was below normal for both storm frequency and storm intensity and overwash into the borrow pit was absent.

During the stormy period both erosional and depositional changes occurred in the borrow area. Between September and February there was a general erosion trend along the east beach adjacent to the borrow pit. The orientation of the borrow pit was such that the northeast corner was closest to the ocean. The east side of the pit trends away from the ocean as it strikes southward. Erosion of the pit area was largely confined to the NE corner. By the

end of October beach scarping in this area had progressed about 50 feet into the pit area and extended some 300 feet along the east side. The 100-foot reach immediately to the south experienced minor overwash and deposition.

The most severe storm of the winter (February 9-15, 1973) resulted in overwash into the pit in the area between Stations 2 + 00 and 5 + 00 (near MP 44.5 and 2250 + 50). During this storm overwash was common along both the east and south beaches adjacent to the borrow pit. Along the south beach two cuts resulted from outflow of pond water. In terms of severity the NE sector was most affected by this storm.

In spite of two subsequent storms of considerable intensity (28 February and 23 March), a rapid build-up of the beach persisted following the February 9-15 storm. Overwash into the pit occurred on both the 28 February and 23 March storms. When pumping began following the March 23 storm the net result of the winter storms had been to increase the volume of material in the borrow area.

In the vicinity of the NE corner of the borrow area elevations ranged from -7.5' to -8.0'. At the conclusion of the stormy period elevations ranged from +2.0 to +3.9. The maximum elevation change due to overwashed sediments recorded was 11.9'. In total an area 200' x 350' of the pond was filled or

approximately 28,000 cubic yards of material. Overwash deposition also occurred in the borrow area external to the 1971 pit area. This deposition, between the east side of the pit and the east beach, ranged up to a maximum of 1.9' approximately 300' to 500' from the beach. As the east line of the proposed borrow area diverged southward from the ocean the surface deposition decreased. A similar morphology of the overwash deposit was recorded for the 15 October 1972 storm. The extremely calm conditions following the March 23 storm precluded subsequent overwash and deposition. In general the east beach widened during this period.

Hurricane Gilda generated surge and waves that resulted in extensive overwash into the borrow pit area (Fig. 4). The full extent of sediment depositions in the pit will be determined as soon as fathometer runs can be completed.

4. Have any sections of the stabilized dunes breached during the pumping period? Was there any correlation between shoreline forms and these breached areas?

Answer: Analysis of overwash events in the nourishment area during the period October 1, 1972 and September 30, 1973 in conjunction with wave height hindcasts indicate that deep water wave heights of 11 feet or more are required to cause overwash in these areas. Seven such events were recorded (see Fig. 2) and occurred on November 8, November 17-18,

January 7-9, February 9-15, February 27-]8, March 21-24 and March 27-28. The most severe storm after March 28 occurred on September 15, 1973 and had a maximum wave height of 8.5' or 2.5' below that required for an overwash event.

During the February 9-15 storm one major and several minor overwashes occurred in the nourishment area. At the major site, near the Buxton motels, an area of approximately 1,700,000 square feet was opened. The adjacent highway was covered with significant amounts of sand. During this event the dunes along 3,000 feet of beach front were destroyed and as such this area was left exposed to subsequent storms of lesser intensity. Several minor sites were also opened immediately to the south of the lighthouse in the vicinity of the Loran Station. These areas, however, were rather small and posed no problem to adjacent facilities.

During the period April 1 through September 30 no sections of stabilized dunes between MP 39 and MP 44.5 have been breached or eroded.

5. What was the pumping schedule for the project?

Answer: Table II shows the pumping schedule for the period 1 February, 1973, to 31 September, 1973. The final yardage of the 1,250,000 yards of material extracted from -15 feet and above in the borrow area, 51,304 yards of sand were excavated from below -15

TABLE II

MONTHLY DISCHARGE ESTIMATES

		Cubic Yards
1.	February 1-28	36,737
2.	March 1-31	46,237
3.	April 1-30	145,652
4.	May 1-31	244,803
5.	June 1-30	160,244
6.	July 1-31	196,408
7.	August 1-31	175,324
8.	September 1-31	244,590
	TOTAL	1,250,000

feet, the contract limit. This material was gratis to the NPS.

6. To what degree did the borrow material differ from the native beach sands?

Answer: On the basis of over 5000 sediment samples taken during the period of the pumping, there was very little difference between the "native" sands and the borrow material. There are natural variations in these samples, as one would expect, but there were no discernible trends associated with the positions of the pump outlet. This verifies clearly that the fill operation was highly effective as measured by the similarity between native sands and the borrow material. Observations of the stratigraphic section of the borrow area indicated that the entire Cape Point spit area is composed of beach and overwash deposits. This was predicted from our pre-nourishment core samples collected last winter.

The relationship between sand grain size and percentage retention of the discharged material was examined. Retention exceeded 100 percent during periods when sand grain size exceeded 0.324 mm. with greatest retention for grain sizes of 0.340 mm. (Fig. 6). On one occasion low retentions (80%) were recorded for large grain size (0.360 mm.). No explanation is immediately available for this lowering of retention of percentage. While the data presented in Figure 6 are scant and can at best account for only a part of

the variation in retention they do suggest that gain size cannot be neglected especially for the smaller size classes.

7. Approximately what percentage of the borrow material remained within the beach energy system?

Answer: Field measurements continue to verify that a high percentage of the fill material is being retained on the subaerial beach and within the near inshore zone.

Based upon surveyed beach profiles and fathometer traverses across the inshore zone, retention figures approach 90% for the entire project. In Figure 7 the accumulative retentions at five intervals during the pumping period are illustrated. It should be noted, however, that loss may not constitute total loss from the system. During the period mid-April to mid-June calculated percentages of retention exceeded 100% and undoubtedly reflects natural beach building processes over and above the discharge additions. At the conclusion of the pumping, approximately 90% of the 1,250,000 cubic yards of sand discharged was in place. Based upon retention estimates the volume of sands in place on the beach system was calculated for five times during the pumping. A comparison of discharge volumes and volumes in place during the pumping period is illustrated in Figure 8.

Accumulative retention percentages were plotted against the highest deep water wave heights recorded

during the period prior to the date of retention calculation. The results of this analysis are presented in Figure 9. A hyperbolic relationship existed between the two variables. It is noteworthy that retentions in excess of 100% occurred only when wave heights were less than 6 feet and that retentions during periods with wave heights of 8 feet or larger retention values were 84%. Clearly the effectiveness of the beach nourishment was dependent on the wave environment and that environment was exceptionally mild during most of the discharge period.

The return interval for storms generating deep water waves in excess of 6 feet, calculated for the discharge period by intervals for which retention estimates were made, was plotted against the retention estimates (Fig. 10). On the basis of this analysis, retention percentages equal to or greater than 100% would be expected only during months when the return interval for 7 ft. or greater storms is less than once in 25 days. Under normal climatic conditions of Cape Hatteras this would only be expected during June, July and August. During 1973 four months (May, June, July and August) met these calm conditions. For retentions greater than 80%, five months normally would have return intervals for 7-foot or greater storms. In 1973, seven months were sufficiently calm to permit retentions in excess of 80%. Clearly

conditions during 1973 were ideal for beach nourishment.

On the basis of the retention estimates and their relationship to the wave environment, it is possible using the climatic normals for the frequency of storms generating deep water waves in excess of 7 feet to estimate the longevity of the 1973 fill (Fig. 11). Given that 3.6 storms of this magnitude or greater occur each year, at the end of one year 53% of the fill should remain and at 2 years 27%, 3 years 16%, and four years 9%. If indeed these estimates are approximately correct, the fill must be viewed in terms of its temporary nature.

8. Have there been significant changes in shoreline configuration?

Answer: The 1,250,000 yards of beach fill resulted in significant impact on the subaerial beach configuration. These changes have been summarized on a month-to-month basis in our progress reports; however, in general terms the shoreline was prograded (that is, built out) seaward between 150 and 300 feet and most of the local irregularities (cuspate) were filled in. Areas adjacent to the pumping sites also benefited. The compartments in the groin field were filled and the rate of shoreline recession south of the lighthouse was checked. The only shoreline area that did not appear to respond was north of the fill. In this reach a large crescentic cell was present during

most of the pumping period--it was impossible to detect any significant "closure" of this shoreline embayment by the added sand.

9. Was there any measureable change in the inshore bar-trough system?

Answer: The nourishment program produced significant alterations in the inshore region; however, its effect upon the outer bar appears insignificant. The nourishment program had two primary effects on the inshore zone landward of the trough. The net profile was shifted seaward by the fill. This necessitated a steepening of the profile slope in this region. No inner bar development was noted, but since this bar is most likely due to storm-induced sand transport and since no major storms occurred after March, its absence is natural.

The detailed fathometer surveys during the monitoring period provided an understanding of the reason for the severe erosion at the Buxton motels in particular. A gap in the outer bar 1000 to 2000 feet long directly offshore of the motels allows high waves to reach the shore before breaking (Fig. 12). A more detailed report of this problem is included as Appendix II. During the period April to September no appreciable modification has been observed in spite of the massive nourishment program. As long as this bar gap remains the motel area will be subjected to overwash and erosion stresses during storms.

10. How often did NASA photograph the area during the period of this pumping? From the NASA photography and small aircraft photo flights were measurable changes detected in areas adjacent to the nourishment site?

Answer: NASA photographed the Outer Banks on January, 1973, February, 1973, May, 1973, June, 1973, and August, 1973. Measureable changes due primarily to the February and March storms were observed. Comparison of the January and February overflights indicates that on the average, 100 to 150 feet of high water line recession occurred during the February 9-11, 1973 storm along Hatteras Island. Severe dune erosion and overwash was noted. Comparison of the February and May imagery indicated that much of the beach erosion had been erased by post-storm accretion due to natural beach-building processes. By August, the beaches were in general as wide as they had been previous to the spring storms.

11. Was there any change in beach-face organisms during the pumping period?

Answer: Counts of the common mole crab (*Emerita talpoida*) along and across the beach in the vicinity of sediment discharge points indicated that population densities were greatest during the summer months and as such a general negative impact on population numbers was not evident. Depressions in population densities were, however, recorded at active discharge points on all occasions when counts were taken. The most significant reductions occurred when the

discharge material was heavily laden with organic matter. No evidence of kills or die-backs were recorded. Evidence was found for abandonment of the beach location in the discharge area and a re-population of beach areas down current from the discharge locations. These findings are detailed in Appendix III and the mechanism of emerita movements briefly summarized below.

Numerous analyses of *Emerita talpoida* population densities indicate that the major impact due to nourishment discharges is a re-distribution of emerita from the discharge area. The area at the point of discharge and immediately to the down current (longshore current) side of the point of discharge are most highly impacted. Mechanisms for the re-distribution of emerita along the beach are:

1) TIDES: emerita moves up and down the beach face with changing water level.
2) WAVES: emerita movements along the beach face are in the direction of the oblique approach direction of swash runup and back wash.
3) DISCHARGE STREAM: the discharge fluid generates a rip current which provides a motion for emerita evacuation of the beach face.
4) RIP CURRENT CELLS: rip current cells associated with the discharge fluid provides

a re-entry fluid motion to the beach approximately 200 feet on both sides of the point of discharge.

5) LONGSHORE CURRENTS: emerita which vacate the beach face via the rip current move along the beach with the longshore current with re-entry to the beach at locations where the current meanders shoreward, approximately 600 to 1000 feet down current from the discharge point. 600 to 1000 feet is approximately the dimensions of the sand wave dimension.

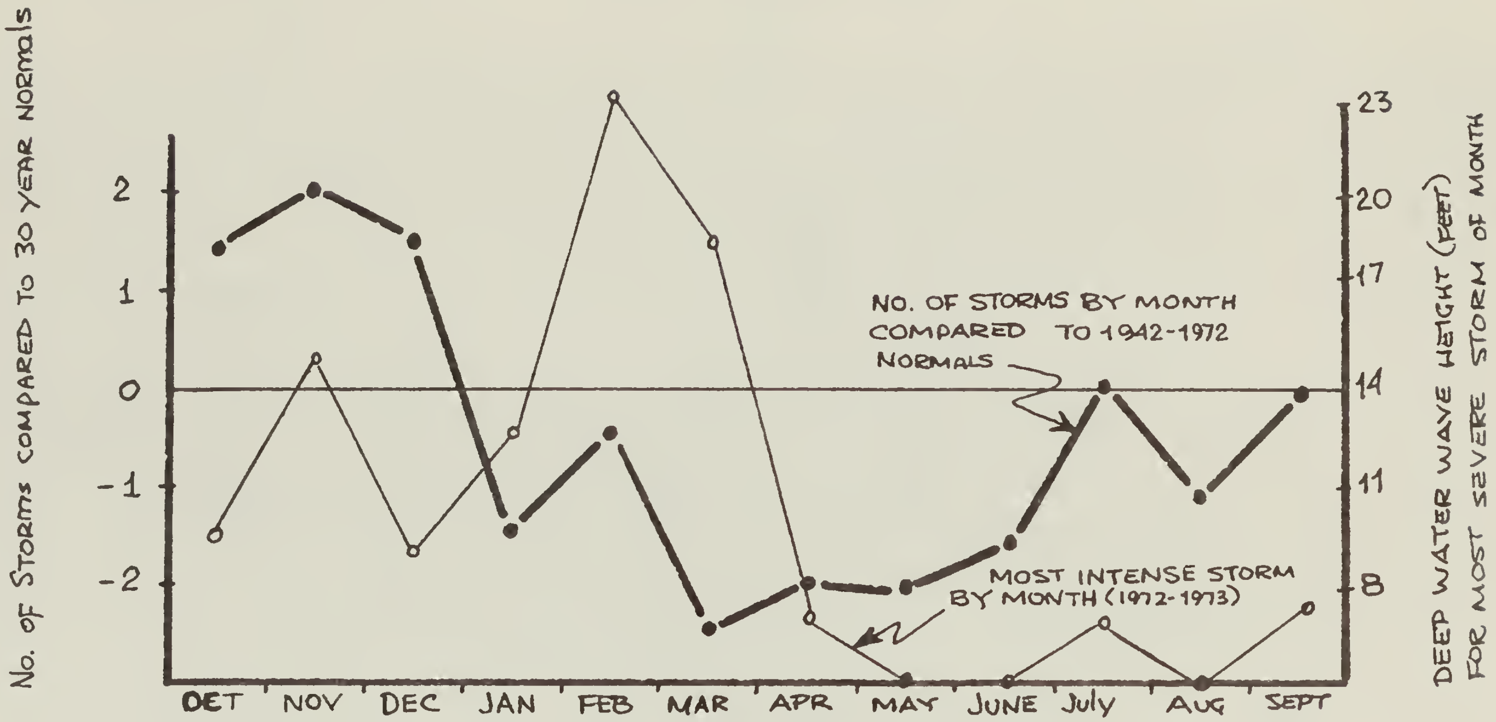

Fig. 1. Storms by Month (Oct. 1,1972 - Sept. 31, 1973) Compared to the (1942-1972) 30 year normals.

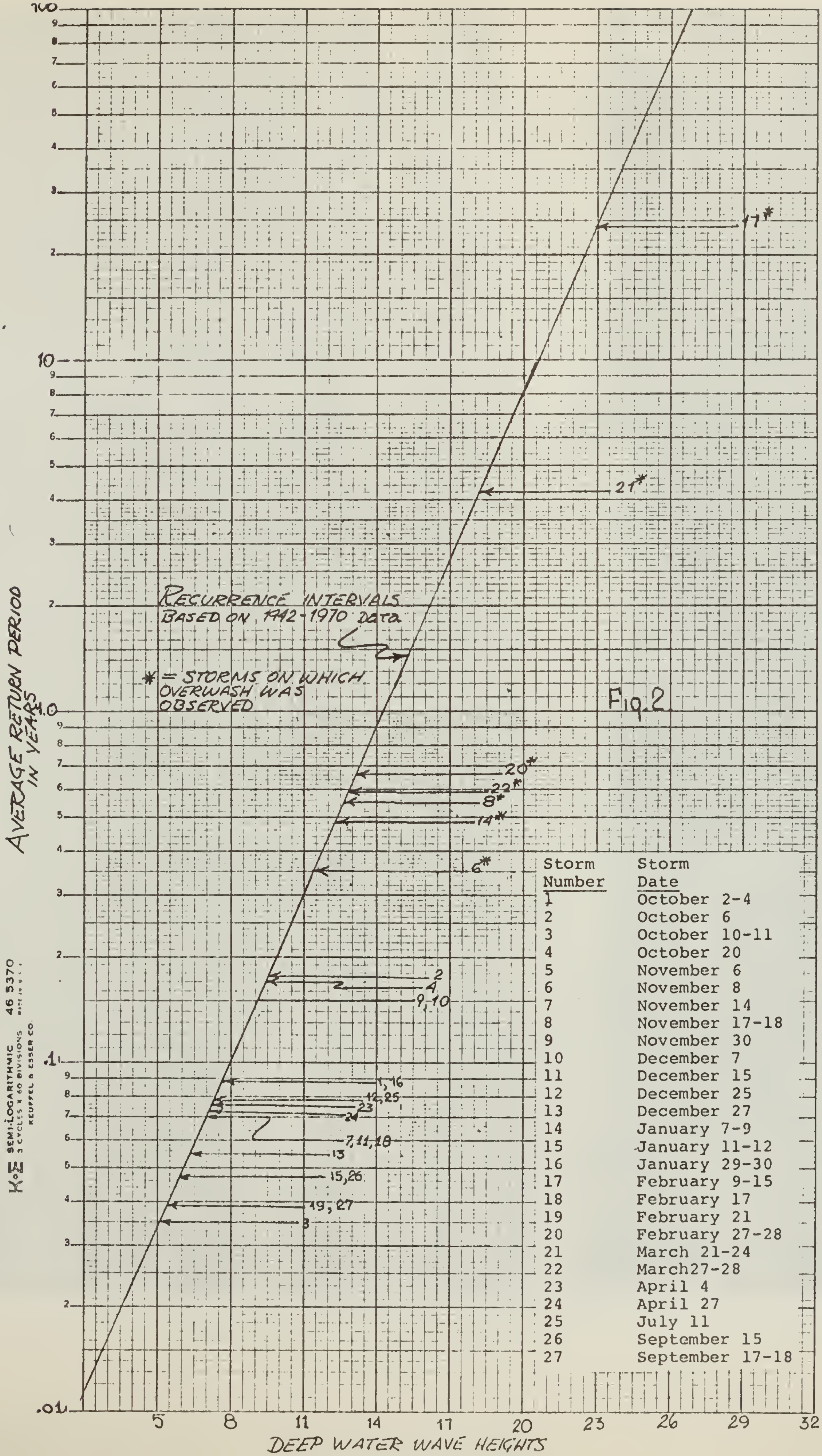

Fig. 2

Storm Number	Storm Date
1	October 2-4
2	October 6
3	October 10-11
4	October 20
5	November 6
6	November 8
7	November 14
8	November 17-18
9	November 30
10	December 7
11	December 15
12	December 25
13	December 27
14	January 7-9
15	January 11-12
16	January 29-30
17	February 9-15
18	February 17
19	February 21
20	February 27-28
21	March 21-24
22	March27-28
23	April 4
24	April 27
25	July 11
26	September 15
27	September 17-18

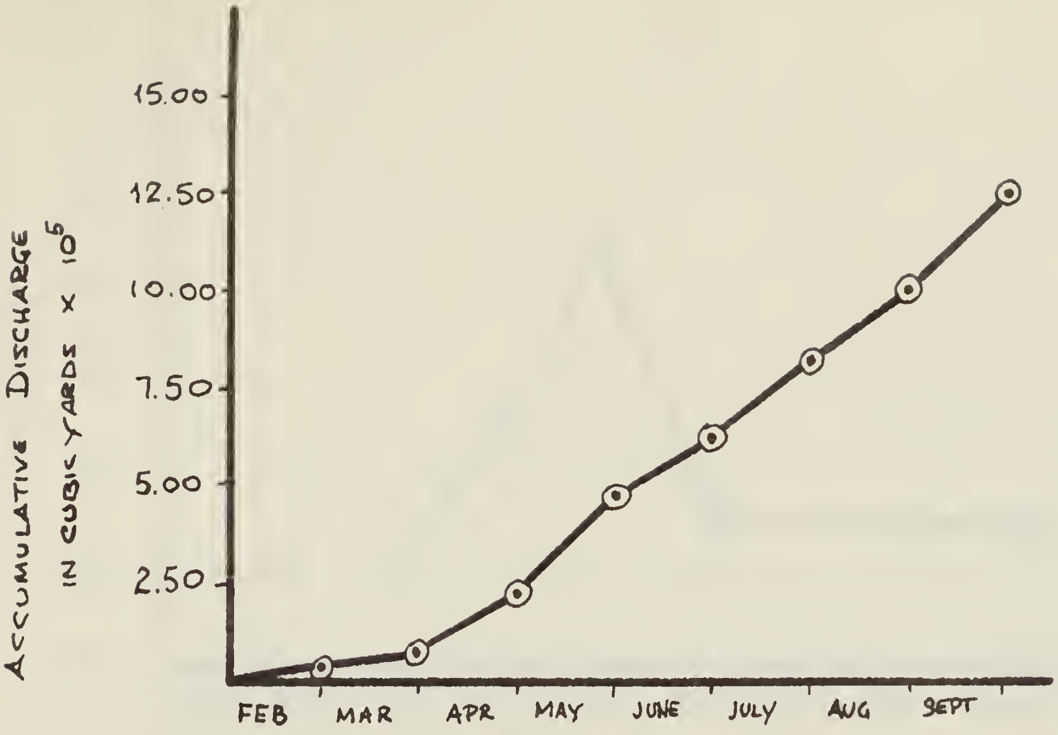

Fig. 5. Accumulative discharge volume by month.

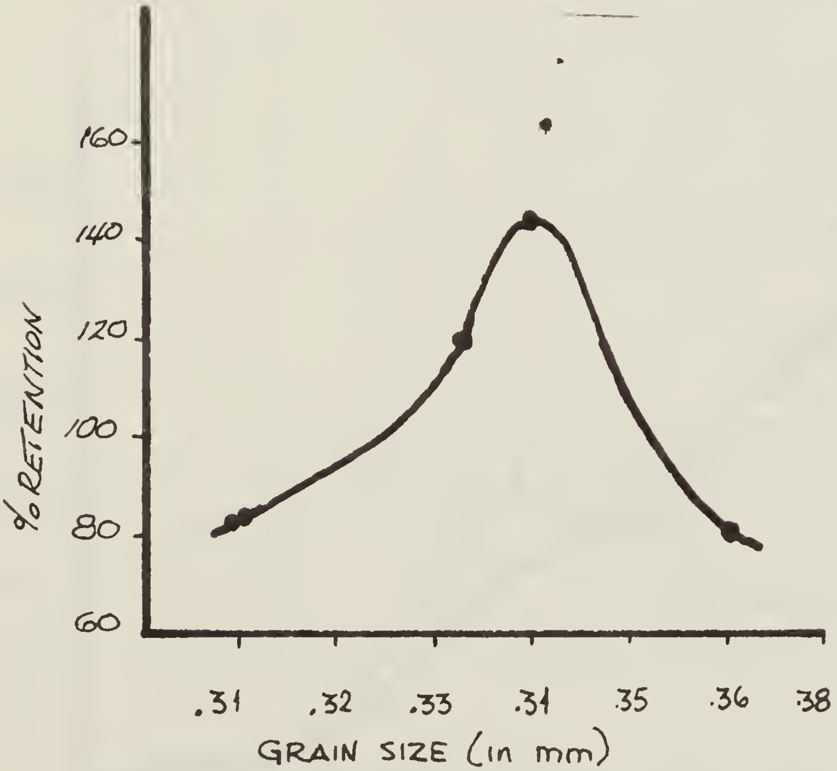

Fig. 6. Percentage retention of fill by grain size of discharge material.

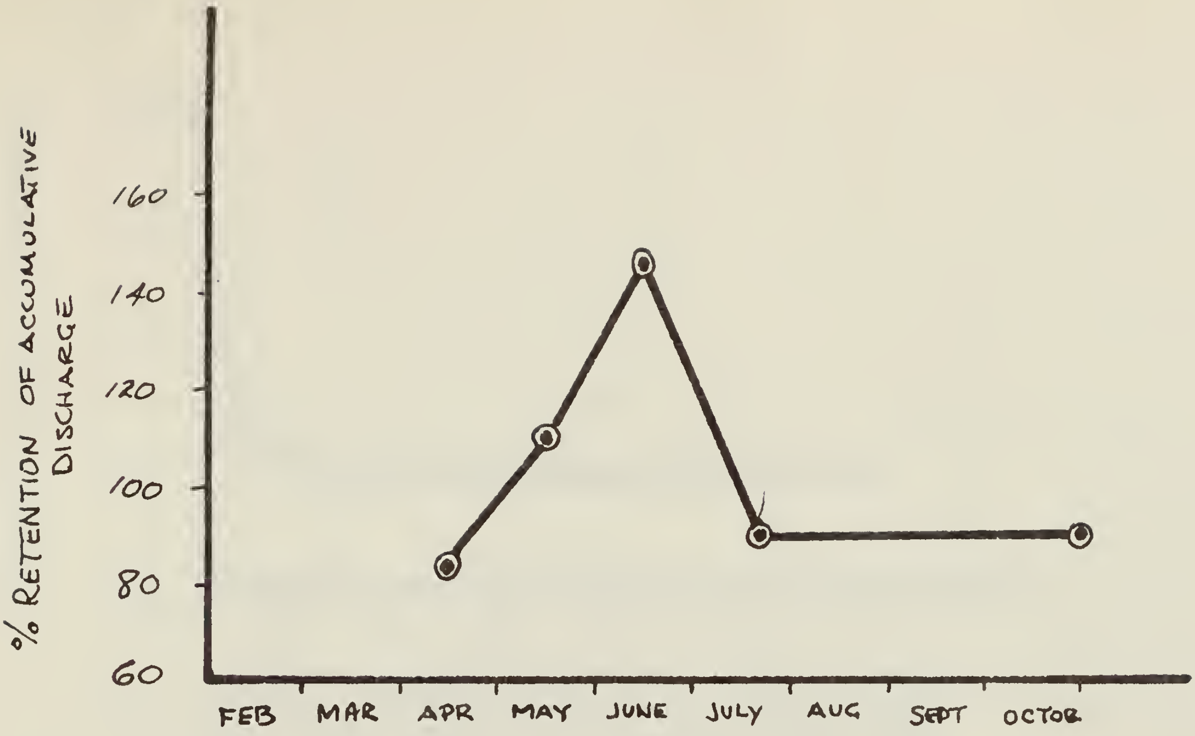

Fig. 7. Accumulative percentage retention of the fill for five intervals during the pumpging period.

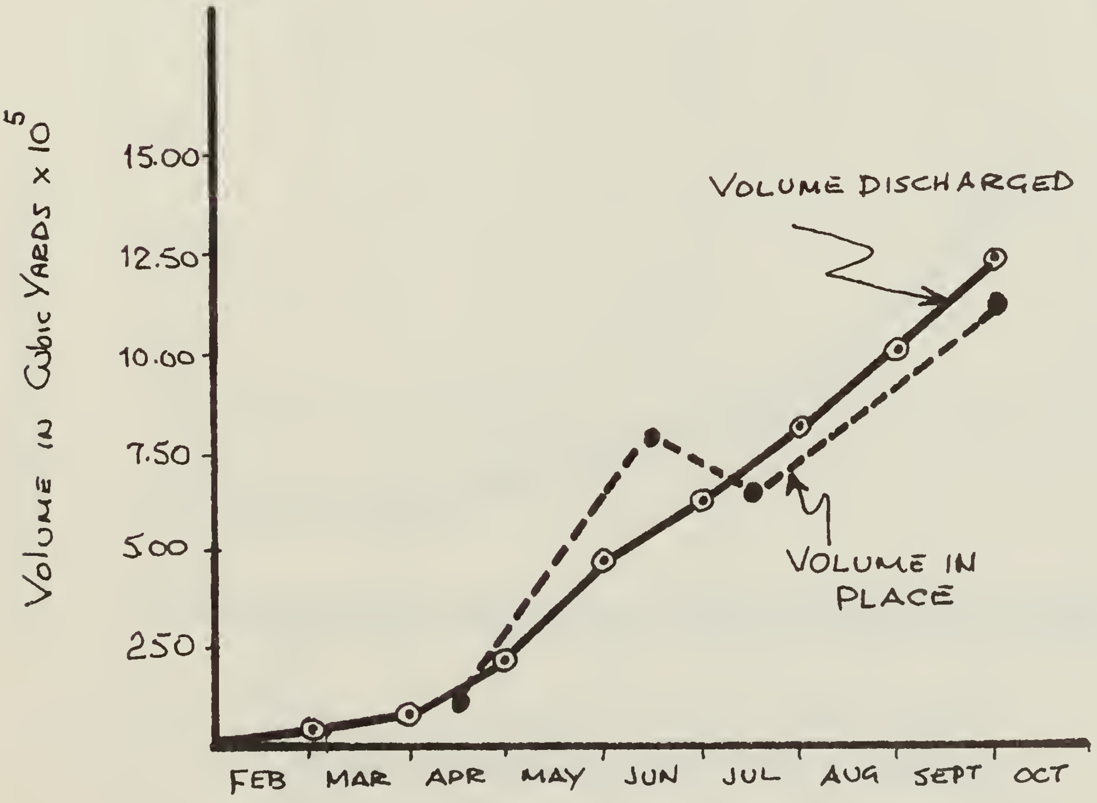

Fig. 8. Discharge volume corrected for percentage retention of the fill.

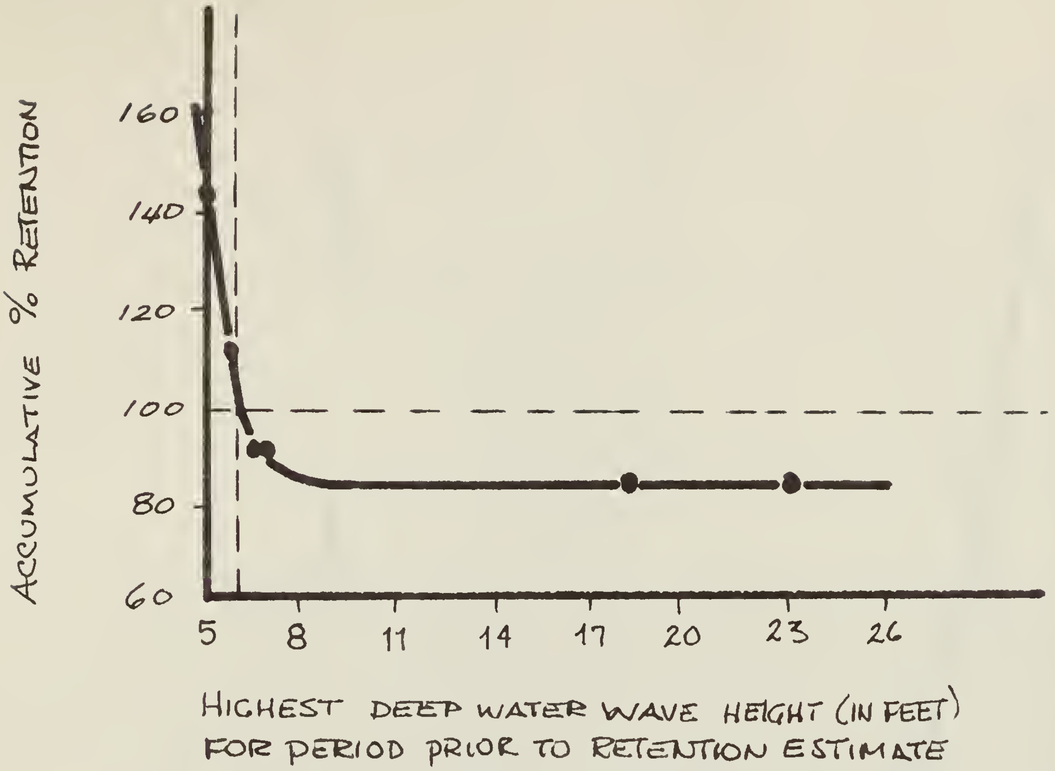

Fig. 9. Accumulative percentage retention of the fill for various wave height environments.

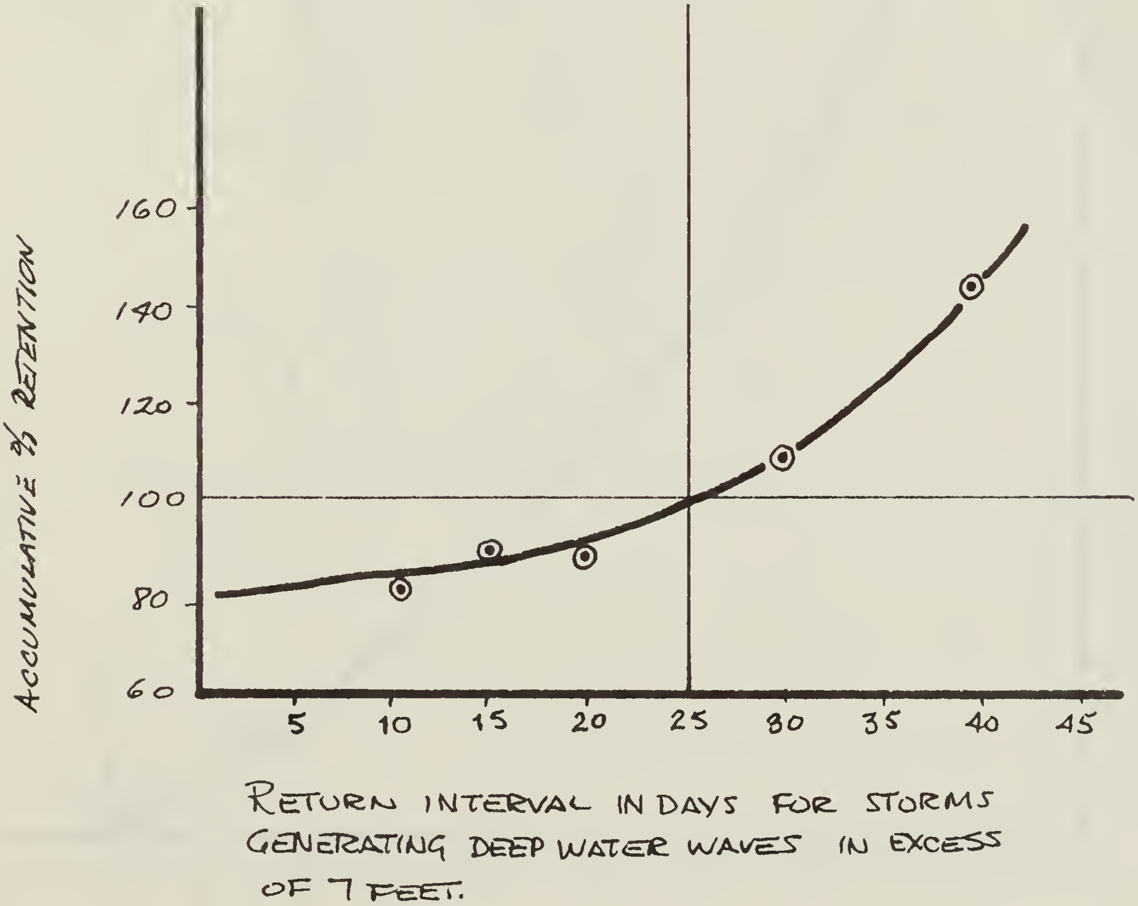

Fig. 10. Fill retention percentages by return interval of storms generating waves in excess of 7 feet during 1973.

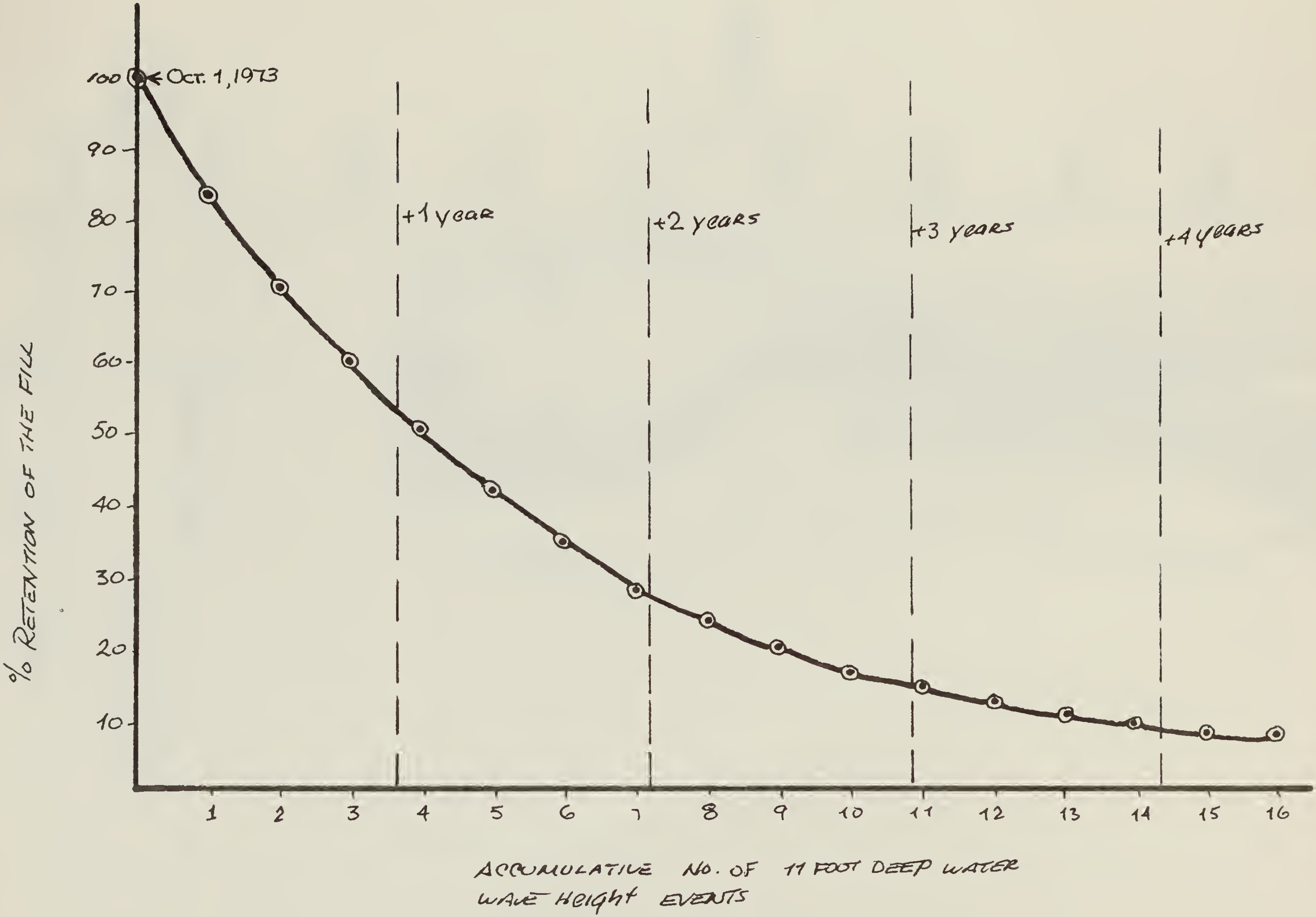

Fig. 11. Estimated retention of the fill for the next five years based upon climatic normals of storms generating 7 foot and greater waves.

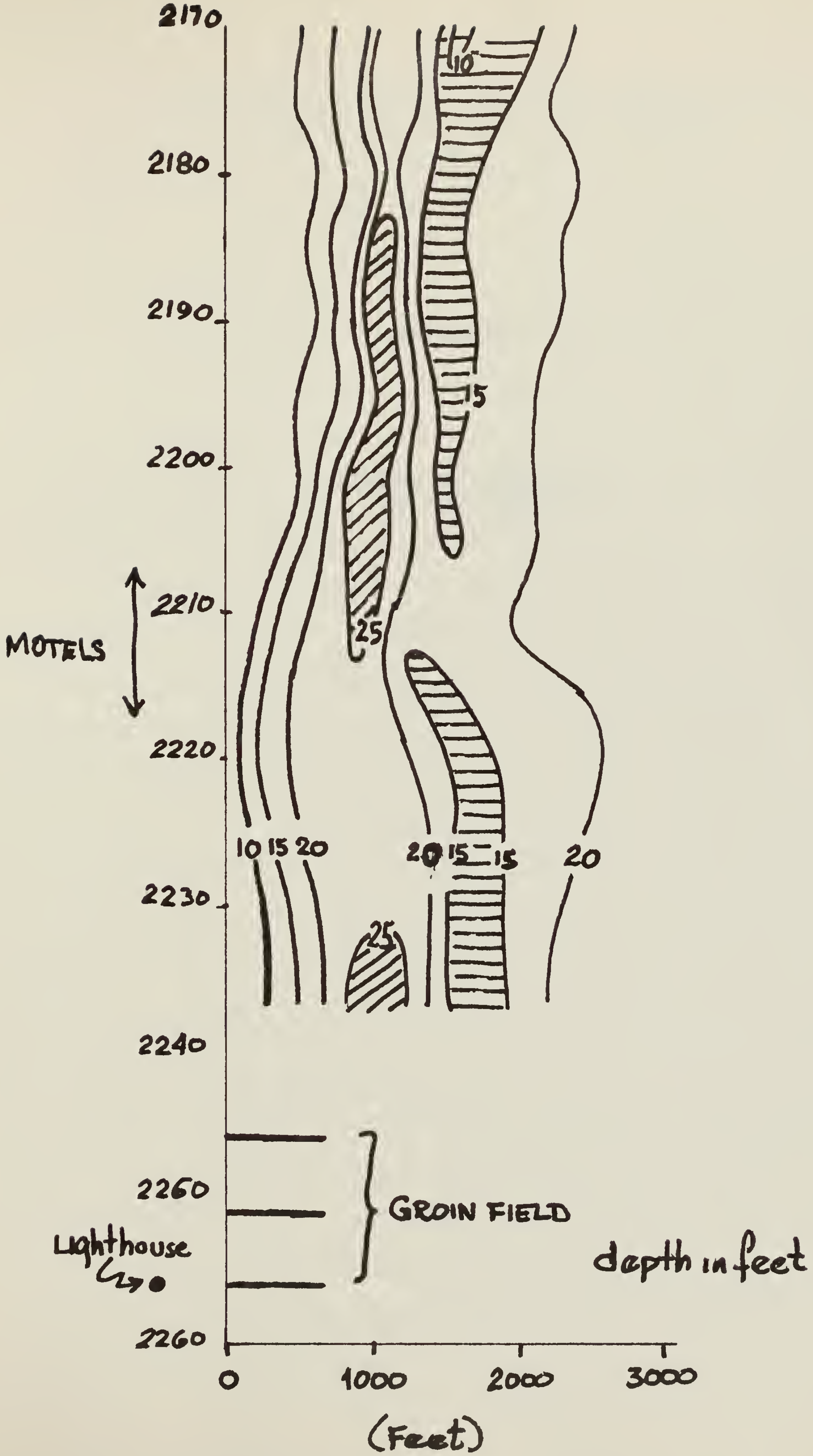

Fig. 12. Nearshore bathymetry in the nourishment area.

APPENDIX I

REPORT ON TROPICAL STORM GILDA

EFFECTS OF TROPICAL DEPRESSION GILDA ON THE BUXTON BEACH NOURISHMENT PROJECT

John Ponton
National Park Service

Winds and waves generated by tropical depression Gilda first reached the Buxton shoreline on Wednesday, 24 October, 1973. By that afternoon some five to six foot waves were reaching the shore. Wave height and wind speed increased during the evening; however, waves of sufficient size to cause overwash did not develop until Thursday.

Some minor overwash began approximately 2 hours before high tide at 0623 E.S.T. Thursday, 25 October, 1973. The volume of overwash increased as the tide rose and continued until approximately 0830. Overwash was general along most of the beach except for the northern one half mile of the beach fill. Fron Station 2195+20 south, water crested the beach fill and moved into the low area landward of the berm, filling this area (see Fig. 1). Swash reached the dunes south of the project area, and there was overwash along the duneless portions of the beach, but there was no significant dune erosion except in the area just south of the groins.

Water and sediment washed into the borrow pit at the N.E. corner, along the last (southern) 1,000 ft. of the East Line, and in a number of places along the south side. The water moved down the back side of the beach and reached as far as the natural pond in the borrow area, as much as 1,500 ft. from the south beach berm.

Large waves and strong northeast winds continued throughout Thursday. Waves estimated to be as large as 12 to 14 feet were breaking nearshore, and waves were breaking on the out bar in as much as 20 feet of water. By evening high tide (1839 E.S.T.) water was reaching the main highway (State route 12) just north of Buxton. This flow was not a direct product of the berm overwash, but rather the low area landward of the fill crest had filled and was overflowing toward the sound (road). Unfortunately, the lowest point of this depression was through the parking lots of the three motels in this area. Overwash continued for approximately two hours of high tide.

On Thursday evening, Gilda was reported to be 275 miles southeast of Cape Hatteras, winds reached up to 70 m.p.h. A storm surge of approximately 1.5 feet was reported at the Avon Pier tide station. By Friday morning when Gilda was 300 miles east of Hatteras and moving N.N.E.

High tide at 0704 am on Friday was also the monthly spring tide, with an elevation of 413 feet. Overwash and surge reached the dunes from approximately 0400 to 1000. Water completely filled the borrow pit and the surrounding low lands of Cape Point. The Water level in the pit reached 4.5 feet to just over 5.5 feet above sea level. Water extended 4,000 feet to the south and between 1 1/2 and 2 miles to the west.

Surge once again reached the road at the north end of Buxton, 2 to 3 feet deep in places. The one half mile of new

road north of town was also covered in a few places. Some minor damage to the road occurred in an area where the low dunes on the east side of the road channeled the overflow into a narrow stream. The flow of water across the road at the north end of town at this time was partly a direct result of surge overwash, for the low area in front of the motels had filled with sand. Fill material was deposited in the parking areas, and a minor amount was transported over the road. It appears that this is the only area where any nourishment material was carried to the sound side of the island. The overwash surges caused some minor structural damage to one of the motels.

As winds shifted to the northwest on Friday, wave height began to drop. Only localized overwash occurred Friday evening, with minor amounts of water reaching the road. By Saturday morning only minor overwash was occurring at the southeast corner of the borrow pit and in front of the motels. Although some large waves were still breaking, the storm was essentially over. Evidence of post-storm deposition was already present, and by Sunday there were no large waves breaking on shore.

Beach Face Response: As expected, the initial response of the beach face to the high energy conditions was to assume a long, relatively flat slope (Fig. 1). This adjustment lead to a significant loss of fill seaward of the fill crest, some lowering and retreat of the top of the fill, and a narrowing of the beach.

A similar response took place outside of the nourished area. Rough estimates of beach narrowing on Friday indicated a landward

retreat of elevation 0.0 feet of between 50 to 100 feet both inside and outside the fill area. As was expected, the maximum beach loss appeared to be in the vicinity of the motels (Station 2210+50). Ocean fathometer profiles taken earlier had shown that the outer bar in this area was significantly lower than to the north or south. This low bar allowed a greater concentration of wave energy on the beach face leading to greater net loss.

Although significant erosion took place on the seaward side of the nourishment material, large amounts of sand were also deposited on the landward side (Fig. 1). Between 20 to 40% of the material lost fron the seaward side of the berm was deposited on the landward portion. *The initial design of the fill configuration had anticipated just such events.* The crest of the pumped material was kept low, between 9.5 and 10.5 feet, and seaward of the pre-nourishment beach face. This configuration was expected to allow the formation of a storm profile (no scarping) with a minimum loss of material and to allow overwash deposition on the backside of the fill.

From the initial profiles completed on 30 October, it appears that there has been a significant net loss of nourishment material. In general, the width of the beach has retreated 30 to 40 feet except in the vicinity of Station 2210+50, where a maximum retreat of 114 feet was measured. The crest of the pumped material has been lowered slightly, but there was no clear trend of retreat in the crest except around Station 2210+50. At Station 2205+20 the crest was lowered by 2 feet and retreated 126 feet.

Material loss also reached a maximum in the motel area.

By 30 October significant deposition on the beach face had taken place. From Station 2190+20 north a well defined depositional berm was present and building upward. An inner bar, which had not been present along any of the pumped beach, had also formed. South of Station 2190+20 an inner bar also appeared to be forming. Landward of this bar was a flat bottom which extended to the beach face, where some deposition was taking place. Beach build up also occurred outside of the nourished area. In fact, at some stations the beach is now wider and higher than before the storm. The only beach outside of the fill area which appears to have suffered significant loss is that south of the groin field, for roughly 2,000 feet.

IMPLICATIONS

The full impact of the storm and the effectiveness of the nourishment project cannot yet be fully assessed. Post-Gilda deposition will significantly alter the beach face. If a significant amount of the fill material that initially moved offshore is redeposited on the beach face, the nourishment project will have passed a severe test.

Borrow Pit Response: Overwash into the borrow pit area lead to some deposition. Most of it was concentrated in the southeast corner where overwash was severest and where the borrow pit is nearest to the ocean. Between 1 to 2 feet of sand was deposited on the back side of the beach leading to the borrow area (Fig. 2).

Deposition decreased away from the storm berm and stopped before the excavated area was reached. Erosion of the flat borrow area took place, accounting for some of the sand deposited in the pit. However, some of the sand was pushed into the pit when the steep banks were graded after the pumping terminated. Although no figure on the amount of eroded sand versus the amount of bulldozed sand deposited in the bottom of the pit has been reached, a net increase in the volume of sand indicates that some storm deposition also occurred. Roughly 750 yards were added per 100 feet along the east line from Station 25+00 north to Station 18+00. Some deposition likely occurred along the south side of the borrow pit with some minor deposition in the northeast corner.

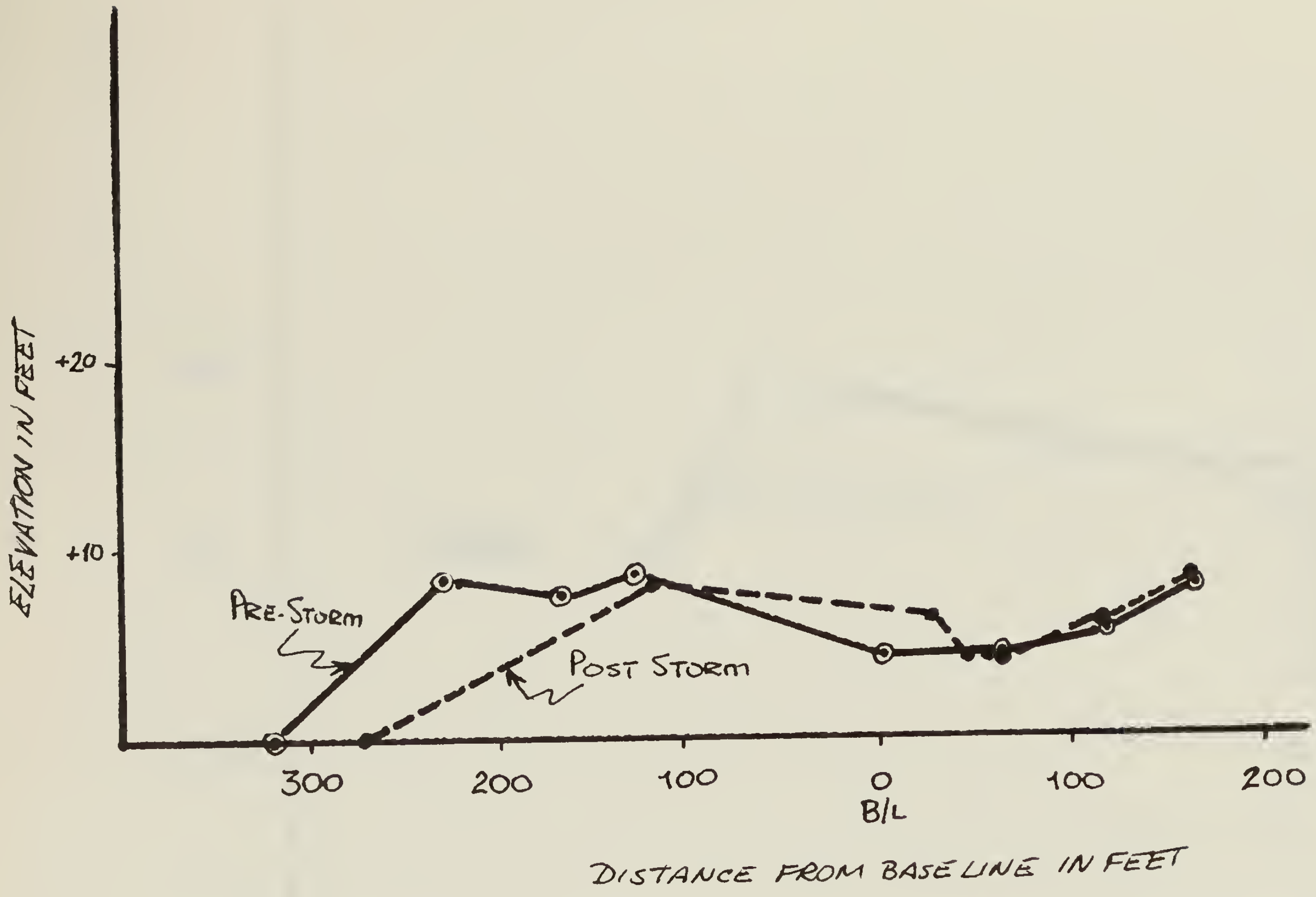

Fig. 1. Generalized changes in beach profiles in the nourishment area.

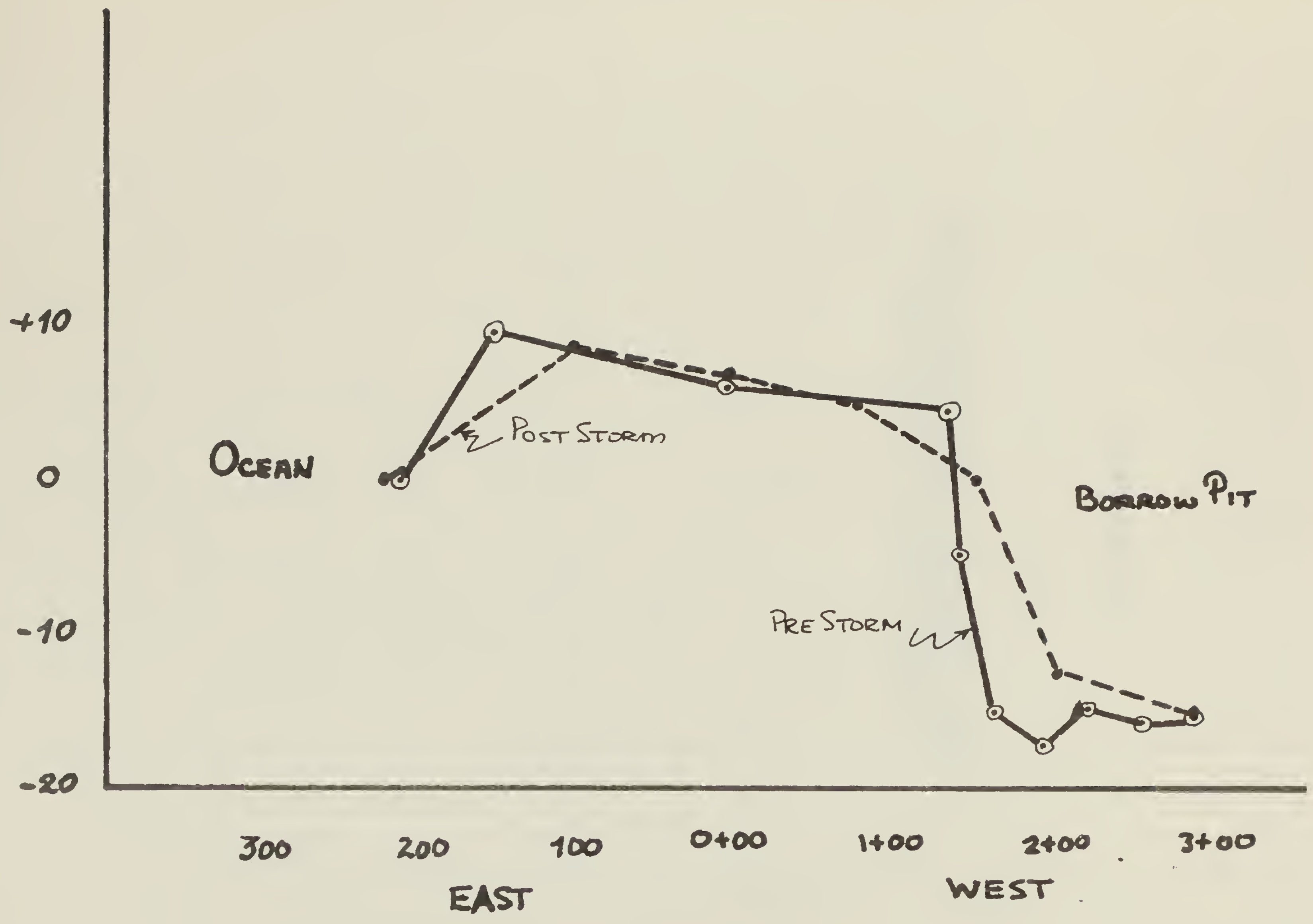

Fig. 2. Generalized changes in the Borrow Pit along the east line between stations 25 + 00 and 18 + 00.

APPENDIX II

RELATIONSHIP BETWEEN LOCALIZED EROSION AND INSHORE BAR CONFIGURATIONS, CAPE HATTERAS, NORTH CAROLINA

RELATIONSHIP BETWEEN LOCALIZED EROSION AND INSHORE BAR CONFIGURATION, CAPE HATTERAS, NORTH CAROLINA

INTRODUCTION

Shoreline erosion along the Outer Banks of North Carolina is the result of a trend in shoreline recession that has continued for over 50 years. Since the turn of the century, approximately 1000 feet of beach has been lost. The 1972 shoreline reached within 50 feet of the extensive development north of the Cape Hatteras Lighthouse, and during recent storms surge actually encroached upon structures. This trend in shoreline erosion is the result of increased storm activity, a rise in sea level, and the lack of a natural sediment source that would renourish the beaches. Two recent nourishment projects were designed to provide some protection to structures and property in the Buxton area via massive insertions of natural beach sands into the system.

Prior to the construction of the Cape Point groin field (1969) in the vicinity of the Cape Hatteras Lighthouse and U. S. Naval Facility, the erosion pattern was one of almost uniform retreat, with a more stable region in front of the LORAN Station. After construction of the groin field, the pattern of erosion changed. The formerly stable reach in front of the LORAN Station has receded

over 200 feet. The reach in the vicinity of the Buxton motels, has undergone rapid erosion, with destruction of the dunes and occasional overwash onto private property as early as 1971. This occurred even though emergency sand bagging and rebuilding of a dune/dike system had been undertaken. These new patterns of erosion are coincident with groin construction. The groins, somewhat unexpectedly, are trapping sediment at the expense of the beaches to either side and as a result of their success, the reach protected by the groins has become stable. Observation from aerial photography indicates that this area now protrudes seaward as a bulge, while the adjacent beaches have retreated inland.

The cause of the localized erosion problem at Buxton appears to be coupled with a lowering of the outer bar height and a deepening of the inner trough, following construction of the groins.[1] This pattern has remained throughout the present beach nourishment program. The implications of this "bar gap" upon the overall effectiveness of the current nourishment project, as well as the future response of the nourishment material, are considered in this paper.

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[1] For a given tidal stage; as the depth of the bar varies with the tide and/or storm surge, so must the maximum wave height transmitted shoreward.

EFFECT OF THE OUTER BAR UPON INSHORE PROCESSES

Along the Outer Banks the primary effect of the outer bar is to filter out the higher waves by causing them to break before they enter the shallow water zone. As the waves shoal, they reach a depth at which they must break, creating turbulence and losing energy. For a given depth, D, waves of height greater than 0.82D must have broken. Thus for a bar depth of 10 feet, no waves 8.2 feet in height or greater can pass shoreward of the bar.

If the bar depth varies along the coast, the maximum wave height allowed to enter the inshore zone must also vary. The effect upon the nearshore processes is not linear, however, because the wave energy available to do work is a function of the square of the wave amplitude (one half height). Thus if two points on the bar crests are at depths of 10 and 14 feet respectively, the maximum height of waves transmitted across the bar system will be 8.2 feet and 11.3 feet respectively. The ratio of amplitudes is $\frac{5.7}{4.1} = 1.39$, but the ratio of energies is of the order $\frac{32.5}{16.8} = 1.96$. The effect is a potential for increased erosion opposite the lower (deeper water) bar.

PRE-NOURISHMENT (1973) CONDITIONS

As indicated earlier, a uniform pattern of shoreline retreat was replaced by severe local erosion in the Buxton motel area after 1969. The formerly uniform

shoreline form in this region became a well-developed crescentic embayment which was present most of the year and appeared stationary. Offshore fathometer profiles indicated the presence of a deep inner trough. By 1971, waves had removed much of the dune and temporary sand bags were placed along the dune line as a protective measure. In the fall of 1971, a nourishment program provided a temporary buffer of sediment, but storms in 1972 removed this material. The larger nourishment program now underway was then planned.

Two factors are worthy of notation. First, the erosion problem was localized and actually stationary; the crescentic sand-wave did not migrate alongshore but appeared locked in position. Secondly, this sand wave was present most of the year. These factors indicate that the cause was stationary, suggesting that the offshore bar system as the likely agent. Greatest impact of the February 1973 storm in the Cape Point region was mostly limited to the motel region. In comparison to other parts of the Buxton area, which received dune erosion and minor overwash, the motel area was the site of a million square foot overwash -- so large, in fact, that it can be seen on ERTS Satellite imagery.

EFFECT OF NOURISHMENT PROJECT

Monitoring of beach and nearshore profiles indicates that the effects of the nourishment program are largely

limited to the close inshore and beach face. Profiles in nourished areas tend to have steeper beach slopes than non-nourished areas, with the beach segment of the profile extended into formerly inner trough areas, yielding a narrower trough. The net shifts are often 300 feet seaward. In general, however, the outer bar does not appear affected by the nourishment materials. There is considerable variability in bar position and beach slope with closeness to the sediment discharge point and variation in wave conditions, as would be expected.

Fathometer profiles were taken in April 1973, May 1973, and July 1973 at the nourishment outlet areas. Examination of the bathymetry estimated from these profiles indicates a significant, persistent bar gap in the vicinity of 2200 + 00. Although some variability in bar heights was noted for the three dates, the differences in depth of the bar crest varied along the reach from 10 feet outside the bar gap area to 16 feet in the center of the cap. The inner trough depth likewise varied, from 20 to 27 feet. As noted previously, such a bar depth differential can have significant impact upon the intensity of the inshore processes. Even though wave heights have been low (1.5 feet) during the summer a crescentic escarpment has been often observed opposite the bar gap.

Although the profile surveys were not designed to provide a detailed, sequential map of the bar system, it is possible to estimate that the bar gap is at least

2000 feet long and is coincident with the area of erosion at the motels. The nourishment project does not seem to be affecting the outer bar system, so it is likely that the bar gap will remain after the project is completed.

FUTURE RESPONSE OF NOURISHMENT MATERIAL

The implications of the data discussed in this paper are that the localized, severe erosion problem at Buxton since 1969, is probably due to a gap or depression in the outer bar opposite the motel area and that the nourishment project has not affected the primary cause of the problem. In essence, the nourishment project has provided a large mass of sediment in front of the motels which will serve as a buffer to the structures and as a temporary sediment source for the longshore current. The future response of this material must now be considered.

As long as the bar gap remains, large waves will be able to attack the beach face directly in the areas shoreward of the gap. The erosion rate in this area will be much higher than adjacent areas with the result being a re-establishment of a large sand wave-like feature. The rate at which the fill is removed will depend upon the severity of future storms, but it is reasonable to expect that a sand wave of the same size as the pre-nourishment one (100 feet amplitude) will migrate inland. The motel area will be subjected to overwash again unless other protective measures are taken. If the rate of erosion is similar to

that occurring after construction of the groins, the effect of the nourishment project may be negated within 2 to 4 years.

At the present time, no detailed systematic mapping of the bathymetry in the entire nourishment area has been undertaken. This alone would require a major research effort. Thus, it is impossible to completely quantify the extent and temporal variability of the bar gap, to draw definitive conclusions about its origin, and to recommend possible remedial actions. Furthermore, before any specific engineering measures can be advanced, it will be necessary to study the impact of the groin field upon sediment transport and current patterns in the Cape Hatteras to Buxton region. If the groins are indeed the cause of this fairly unique and persistent inshore bar-trough situation, this may require substantial protective measures to combat the perturbation in the natural system caused by the groins. Unless the reasons for the localized erosion problem are fully understood, future efforts to protect this area may be ill-chosen and marginally effective. Any alteration of the present groin system or any consideration of expanding the groin field should only be undertaken after extensive investigation.

APPENDIX III

BEACH NOURISHMENT IMPACT ON THE COMMON MOLE CRAB

ABSTRACT

The ecological impact of beach nourishment on the common mole crab, *Emerita talpoida,* determined through population census surveys, was found to be a reorganization of the organisms along the beach rather than an increase in population mortality. Reductions in population densities at and immediately adjacent to the down-current side of the point of discharge were recorded. The population depression was restricted to a 200-foot section of the beach. Population 600 to 1,000 feet down the beach in the direction of the longshore current increased, indicating a migration of mole crabs in response to nourishment. Tidal, wave, and current motions were found to play an essential role in reducing the mortality of the mole crabs and permitting migrations associated with beach nourishment. Population numbers at the discharge site recovered within a few tidal cycles. Repopulation organisms come apparently from the unimpacted side of the discharge site through swash motion.

ACKNOWLEDGMENT

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SUMMARY

Beach nourishment does not increase mortality of *E. talpoida* but causes their migration from the discharge site with the longshore current. Mole crabs repopulate impacted site areas within a few tidal cycles of discharge termination.

KEY WORDS

Ecological impact

Beach nourishment

Mole crabs

Longshore currents

BEACH NOURISHMENT IMPACT ON THE COMMON MOLE CRAB

by Bruce Hayden[1] and Robert Dolan[2]

INTRODUCTION

Since passage of the National Environmental Policy Act of 1969, determination of the ecological impact of engineering projects involving alteration of the natural landscape has become both a practical and a legal necessity. The widespread occurrence of shoreline recession (3) has precipitated many engineering projects designed to check "beach erosion." Beach nourishment, sea walls, breakwaters, and groin construction are currently underway in several coastal locations. Of the four erosion-control techniques, beach nourishment is particularly attractive in that the character of the shoreline is little changed (1); however, the ecological impact of discharging thousands of cubic yards of sand onto the beach is little known.

In 1972, under the sponsorship of the National Park Service, the authors were contracted to assess the ecological and physical impact of a large beach-nourishment pro-

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gram at Cape Hatteras, North Carolina. The location of the nourishment site is illustrated in Figure 1. Since all aspects of the beach-face ecology could not be monitored, it was decided to concentrate on the common mole crab. As an inhabitant of the swash zone, *Emerita talpoida* is vulnerable to beach-face modification and thus likely to exhibit a response to such activity. In addition, *E. talpoida* is an important link between subaqueous and subaerial food chains; it feeds on plankton in the swash zone and, in turn, is subject to predaceous shore birds. Significant disruption of *E. talpoida* populations could have wide ecological implications to the barrier island ecosystem.

HISTORY OF CAPE HATTERAS EROSION AND THE BEACH NOURISHMENT PROJECT

It has long been recognized by coastal engineers that beach erosion becomes a serious problem only when man-made structures are threatened by shoreline recession. Public concern about recession along the Outer Banks of North Carolina can be traced back to the early development of the beach front property during the late 1930's and 1940's. ** Serious problems were inevitable as the erosional forces along the mid-Atlantic are highly variable and time-dependent; and the line of development, once it had been established along the Outer Banks, remained fixed.

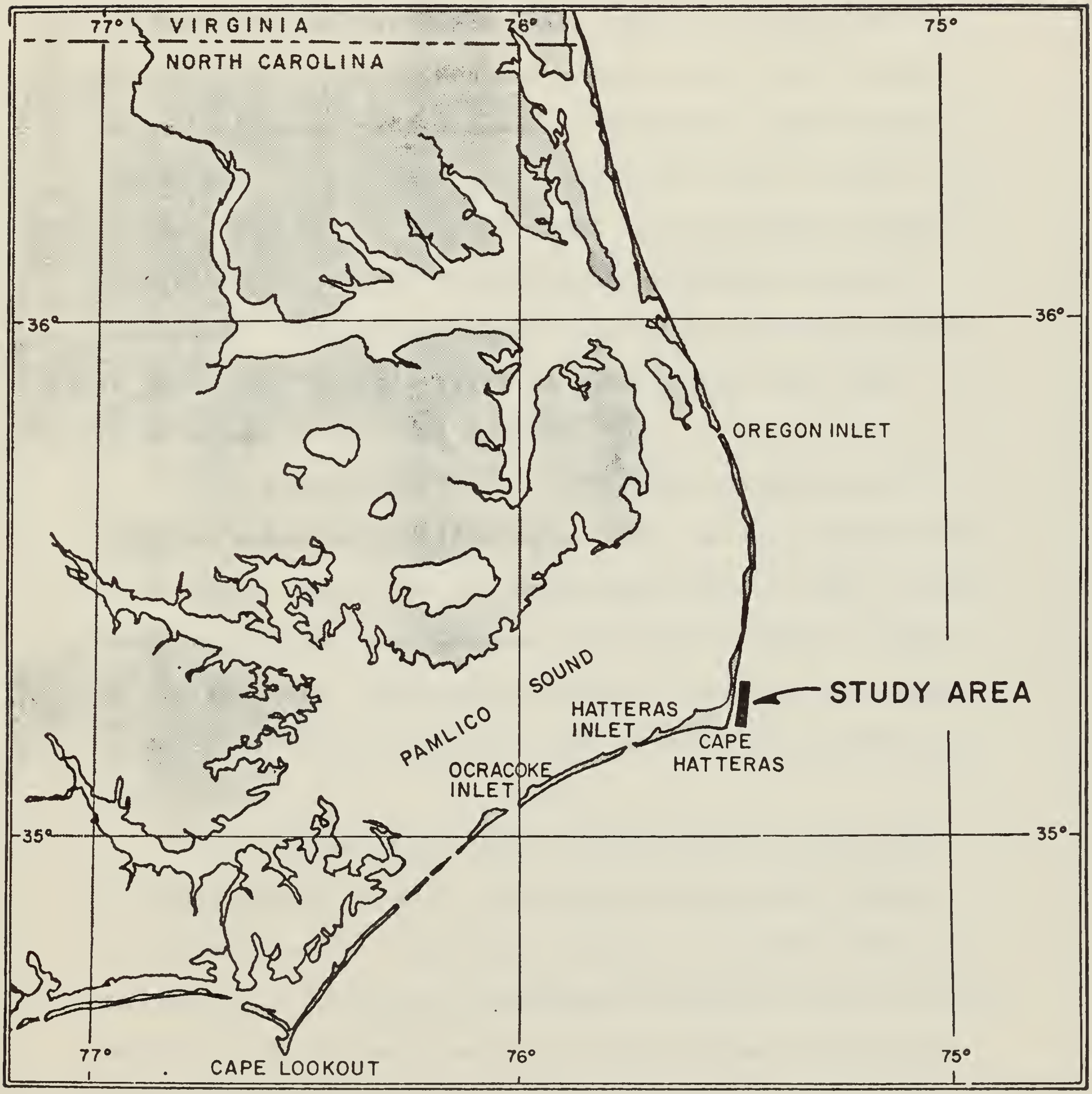

FIG. 1.--Location Map: Outer Banks of North Carolina

Narrowing of the distance between the line of development and the active surf zone at Cape Hatteras reached a critical point during the mid-1960's. Large segments of the man-made barrier dunes which had been constructed in the late 1930's were lost and oceanic over wash became a constant threat. The distance between the Cape Hatteras Lighthouse and the surf zone reached 256 feet in 1966, as shown in Figure 2. With reversal of this trend unlikely and relocation of the shoreline developments virtually impossible, the National Park Service contracted in 1966 to have 312,000 cubic yards of sand placed along the beach areas of greatest concern.

The material for this restoration program was extracted from a large tidal delta that had been deposited by an inlet during the Ash Wednesday storm of 1962. However, the borrow material was too fine to remain as part of the subaerial beach system and the quantity too small to have significant impact on the inshore bar-trough system.

This initial experiment in nourishment proved to be ineffective; by 1967, continuous erosion had placed the Cape Hatteras Lighthouse and the U. S. Naval facility at Buxton in positions vulnerable to wave and surge forces. Following the recommendations of the Coastal Engineering Research Center, Army Corps of Engineers, the Navy con-

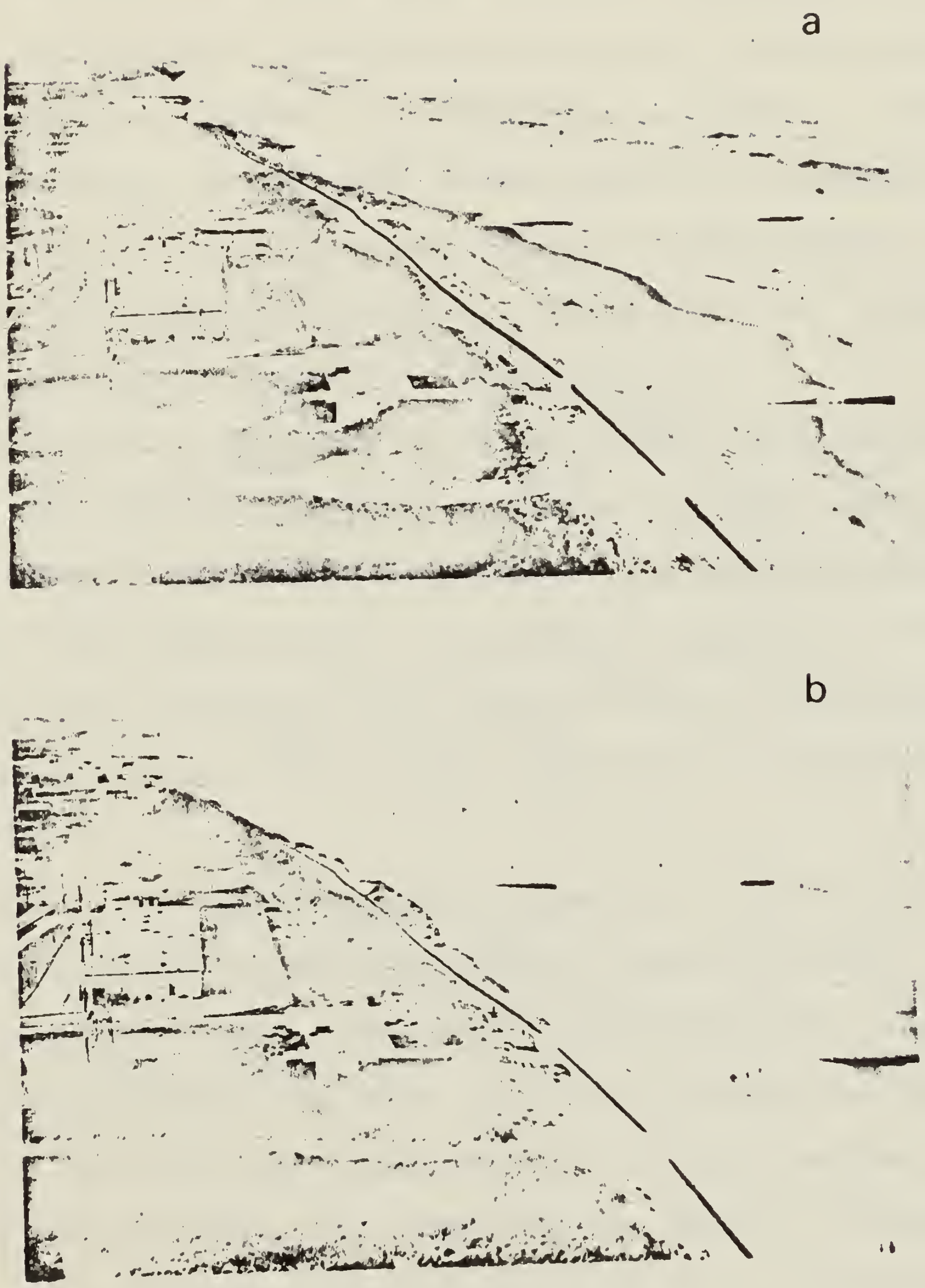

FIG. 2.--Photos Taken from Cape Hatteras Lighthouse

a. Pre-nourishment: Jan. 1973

b. Post-nourishment: Sept. 1973

tracted to have three permanent groins constructed during the summer of 1969 within the problem area, as illustrated in Figure 2.

The groins, which required several adjustments in design, did provide protection for the Navy facility and the lighthouse; however, the shoreline adjacent to the north and south of the groin field continued to receed at rates equal to or in excess of those recorded earlier. The National Park Service continued a "hold-the-line" strategy using sand bags and spot-dune construction.

During the winter of 1970, the erosion problem north of the Cape Hatteras Lighthouse became so severe that another beach-nourishment project was planned and implemented in the fall of 1971. Instead of returning to the 1966 project borrow site, the Pamlico Sound tidal delta, sand was extracted from the Cape Point spit, illustrated in Figure 3.

This 1971 nourishment was effective in that the material remained on the beach for a longer time than the 1966 nourishment did. Although the 500,000 cubic yards added during the 1971 project was nearly double the amount added in 1966 (312,000 cubic yards), the beach system was still proportionately too large for the amount of material added. The present project is designed for a sufficient volume of material (1,250,000 cubic yards) to have much

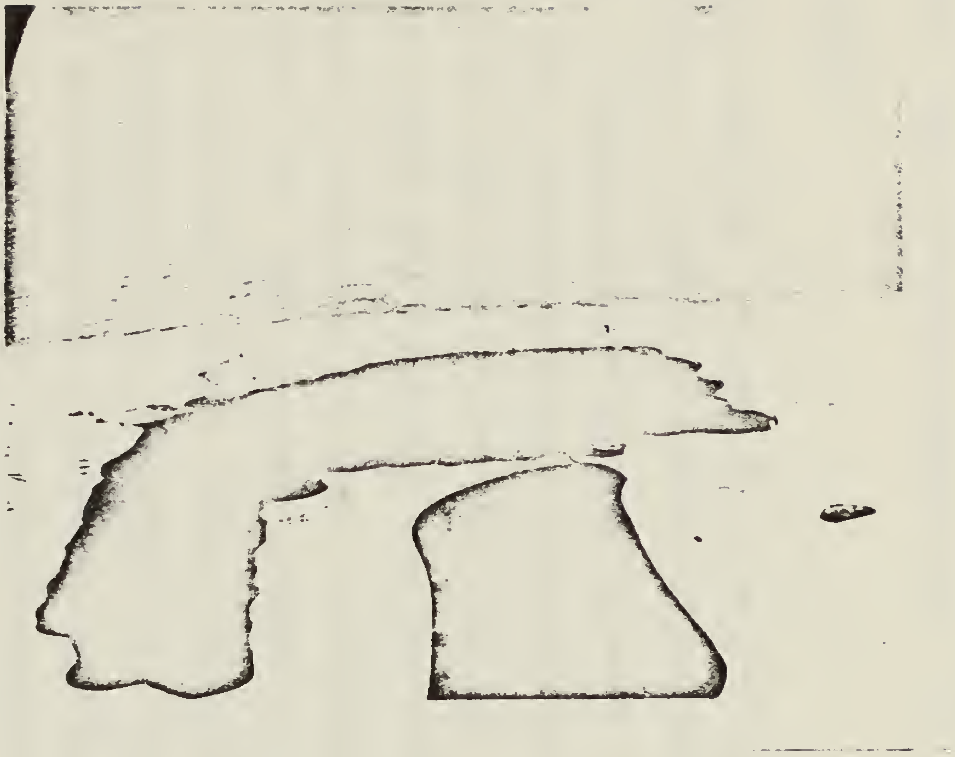

FIG. 3.--Airphoto of Cape Hatteras Spit Borrow-Site Area

greater impact on the beach energy system.

The Cape Point spit borrow site has proven to be an excellent source of nourishment material. Analysis of more than 2,500 sediment samples, collected from the discharge points and from sites reflective of natural conditions, indicates that it is virtually impossible to separate the nourishment material from the natural beach sands. ***

EMERITA TALPOIDA

Emerita talpoida, the East Coast sand or mole crab.--This crustacean is a common inhabitant of the beach-face swash zone. Burrowing backwards into the sand, it feeds by extending large, feathery antennae just above the sand surface during the swash backrush and intercepting food materials. As the tides change, the crabs must move up or down the beach to remain in the location where the duration of backrush is greatest (2). This movement occurs *en masse* and usually on a single wave uprush. Since the position of the *E. talpoida* population on the beach face is a function of tidal stage, wave height, wave direction, and beach slope, the design of proper sampling procedures required analysis of population densities across the beach face.

Sand surface samples of 77.5 in^2 (500 cm^2) were taken at three-foot intervals from the beach berm to the most seaward point of exposed sands on swash backrush. Both a steep and a shallow beach face were sampled. The results of

these analyses are presented in Figure 4. On the steep beach a single population-density maximum was observed approximately 18 feet from the most seaward sample point. On the flat beach, a population-density maximum was observed in the same vicinity; however, two lesser maxima were also observed which undoubtedly relate to the complexity of approaching waves as reflected in distinct swash areas in the shallow beach. In order to assess the impact of beach nourishment on *E. talpoida*, it was decided that samples should be taken in the center of the most active swash area of the beach. While fewer organisms were found on the shallow beach than on the steep beach, density at the point of population maxima differed little.

THE IMPACT OF BEACH NOURISHMENT ON *E. TALPOIDA*

In order to assess the impact of beach nourishment on *E. talpoida*, four samples of 77.5 in^2 (500 cm^2) each were taken at the center of the zone of active swash at 36-foot intervals up and down the beach from the point of sand discharge. The results of this survey are presented in Figure 5. This sampling procedure was repeated for three different sand-discharge locations. At each of the three sites, population densities were preferentially depressed to one side of the point of discharge. In the cases of the June 18, 1973, and July 20, 1973, discharge

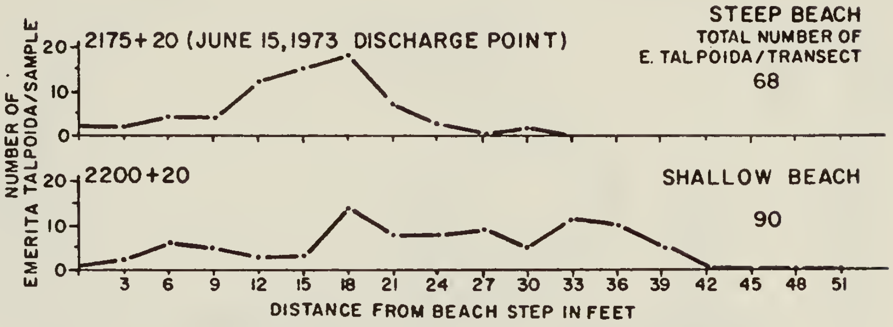

FIG. 4.--Results of Beach-face Samples Analysis

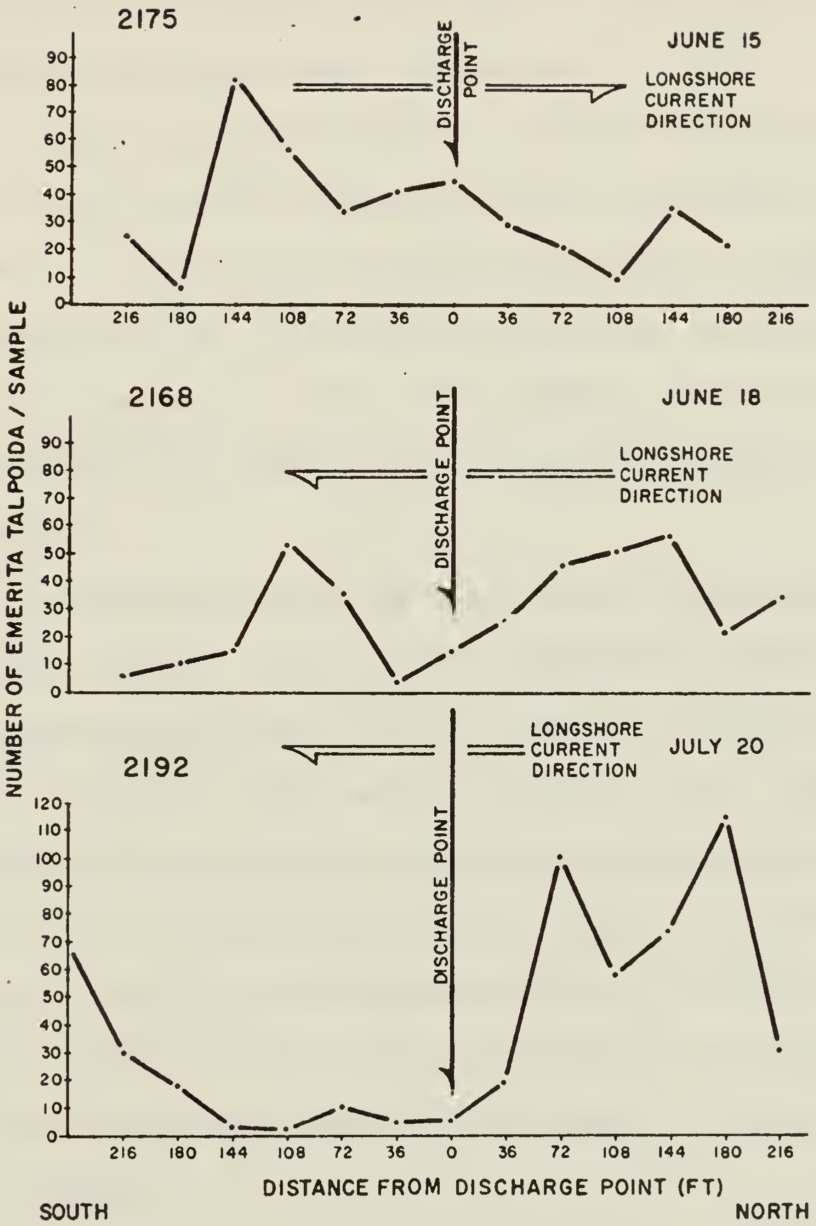

FIG. 5.--*Emerita talpoida* Densities Along the Beach Adjacent to Sand Discharge Locations

points, the population densities were depressed to the south of the discharge sites while at the June 15 site, population densities were depressed on the north side. On the days preceeding the June 18 and July 20 samples, waves were from the northeast with a southward longshore current. On the days preceeding the June 15 samples, the waves were out of the southeast and the longshore current moved to the north. Thus, the impact on *E. talpoida* was restricted to the down-current side of the point of sand discharge.

The magnitude of the population depression due to discharge varied. On June 15, population densities on the impacted side were 59% of those on the non-impacted side; on June 18, 53%; and on July 20, 17%. While the non-impacted-side population densities were considerably higher on July 20, the magnitude of the impact was also much greater. Field observations taken on the days preceeding July 20 indicated that large quantities of organic matter from the borrow pit were incorporated in the discharge water material.

In order to insure that the observed impact along the beach was not due to sampling error with respect to population positions across the beach, transects at three-foot intervals across the beach were taken 36 feet north and south of the July 20 discharge point. At the time of the July 20 discharge, the longshore current was out of the

north with the steep beach to the south and the flatter beach to the north.

It was noted that the population structure was unimodal to the south of the discharge point and trimodal to the north. In spite of this difference, the depression in population density on the down-current side of discharge was clearly evident and is illustrated in Figure 6. While the total number of organisms observed on the impacted south side was 30, 75 were observed on the north side. The 40% reduction in population density is consistent with the 53% observed for the along-the-beach sampling procedure.

While there is considerable evidence for a depression in population densities of *E. talpoida* immediately down beach from the point of discharge of nourishment material, the fate of the impacted mole crabs remains uncertain. The lack of dead crabs on the beach-face in the impacted area suggests that they are not subject to massive kills. It is known that, when stranded on the upper beach with the retreating tides, the mole crab will bury itself several inches into the sand and await the following rising tide (1). However, deep samples from the nourishment area indicated that the mole crab vacates the impacted beach rather than burrow into the sand. If a migration from the beach via the surf zone and subsesequently onto another beach location does occur, it should

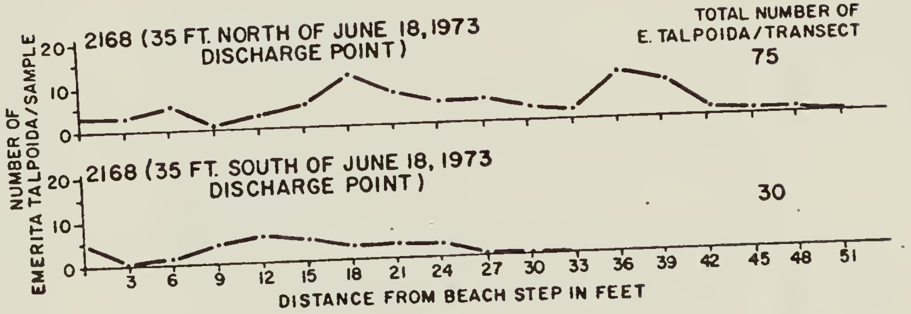

FIG. 6.--*Emerita talpoida* Densities Across the Beach Adjacent to Sand Discharge Point

be detectable. Samples taken at 200-foot intervals suggest that this movement may be actual. The results of these analyses are illustrated in Figure 7.

On six occasions sand discharges were accompanied by high population densities approximately 600 to 1,000 feet down the beach from the point of discharge. In three of the six instances, northeast waves and southward longshore currents occurred at the time of discharge; and, in the remaining three cases, southeast waves and northward longshore currents took place. In all six cases, the elevated numbers of *E. talpoida* observed were in the down-current direction at a distance of between 600 and 1,000 feet. This dimension is consistent with sand-wave shoreline meanders in the area and suggests that the mode of transport and re-entry onto the beach face may be the response of the bar system to the prevailing longshore current.

CONCLUSIONS

Although the studies reported here were essentially experiments of opportunity, sufficient data were assembled to construct a model for the impact of beach nourishment on *E. talpoida*:

1. On discharge of nourishment materials, the sands are transported across and down the beach via swash and

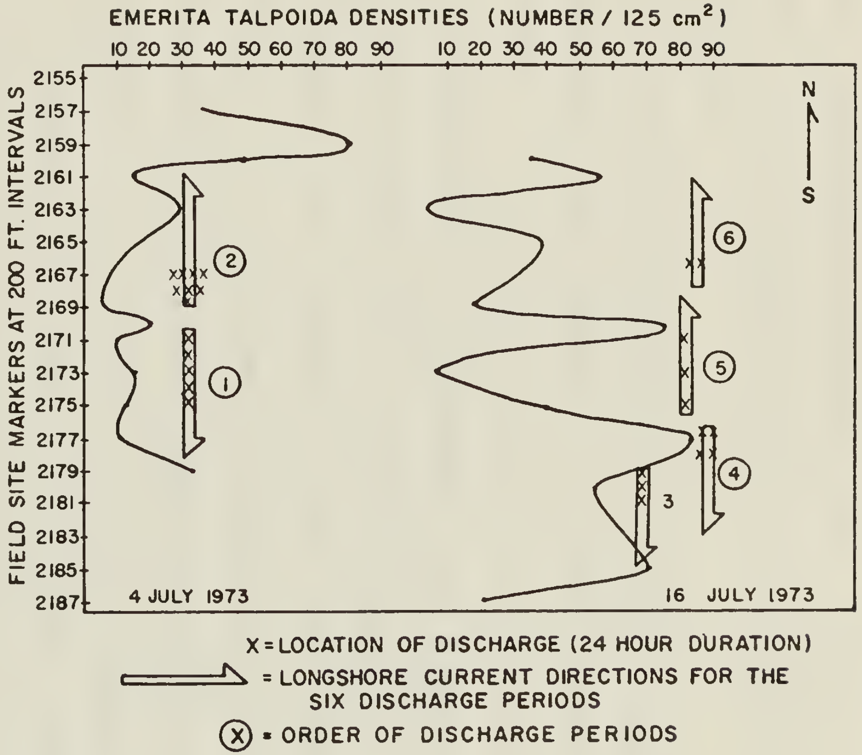

FIG. 7.--*Emerita talpoida* Densities Along the Beach Following Consecutives Times of Discharge

longshore currents. (The nourishment is permitted to be redistributed after discharge by the natural processes of sand movement on the Cape Hatteras project). In the area immediately down-current from the point of discharge (0 to 216 feet), population densities of *E. talpoida* are reduced due to their movement out of the stressed area and to some kills.

2. *E. talpoida* move with the longshore current and re-enter the swash zone some 600 to 1,000 feet down the beach resulting in increased densities at that location.

3. On termination of discharge, the impacted area immediately down-current from the discharge point recovers rapidly. Movement of *E. talpoida* on the non-impacted side of the discharge is up and down the beach face with the tides and horizontally with the swash with an overall component of motion in the direction of the longshore current. At the point of impact, *E. talpoida* numbers are returned to normal within one day (two tidal cycles) while the remainder of the impacted area becomes repopulated within a week or two.

While a specific ecological impact of beach nourishment has been documented, it should be emphasized that the impact involves the redistribution of the mole-crab population rather than a massive mortality. The magnitude of

this impact is apparently greater when the discharge material contains a large amount of fine material or organic matter. The severity of the impact of beach nourishment is tempered by the large number of *E. talpoida* along adjacent beach areas which can move into the impacted area which results in the rapid recovery of *E. talpoida* following termination of nourishment. Thus the ecological impact on *E. talpoida* is of short duration and poses no impediment to the use of this form of shoreline protection as an engineering measure.

Since the distribution of nourishment sands was left largely to the natural distributive mechanisms of the swash zone, large earth-moving equipment was not used on the beach surface. In similar manner the fate of the impacted mole crabs was controlled largely by the prevailing circulation patterns. *E. talpoida* population increases 600 to 1,000 feet down beach are consistent in dimension with the size of large, shoreline meanders in the area. It is likely that the meanders in the longshore current associated with these shoreline forms also play a role in the redistribution of the impacted mole crabs.

LIST OF FIGURES

FIG. 1.--Location Map: Outer Banks of North Carolina

FIG. 2.--Photos Taken from Cape Hatteras Lighthouse

- a. Pre-nourishment: Jan. 1973
- b. Post-nourishment: Sept. 1973

FIG. 3.--Airphoto of Cape Hatteras Spit Borrow-Site Area

FIG. 4.--Results of Beach-face Samples Analysis

FIG. 5.--*Emerita talpoida* Densities Along the Beach Adjacent to Sand Discharge Locations

FIG. 6.--*Emerita talpoida* Densities Across the Beach Adjacent to Sand Discharge Point

FIG. 7.--*Emerita talpoida* Densities Along the Beach Following Consecutive Times of Discharge

APPENDIX.--REFERENCES

1. Govatos, G. and Zandi, I., "Beach Nourishment from Offshore Sources," Shore and Beach, Vol. 37, No. 2, 1969, pp. 40-49.

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